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Renovated Ballistic Equation of Ejected Blocks and Its Application to the 1982 and 1983 Sakurajima Eruptions

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We propose a ballistic equation of ejected volcanic blocks that is renovated by considering air resistance, wind velocity and direction dependence of the initial velocity. In the equation, we treat the air resistance as a vector that coincides with the opposite direction of flight. By comparing the calculated results based on the equation of motion and the observed data, such as spatial distribution of landed blocks, initial velocities by successive photos and so on, we tried to reproduce kinematic aspects of the ejected blocks at the 1982 and 1983 eruptions of Sakurajima Volcano, Kyushu, Japan.

Key words: ballistic equation of volcanic blocks, air resistance as a vector, Sakurajima volcano

1. Introduction

Volcano-energetic study is very important for discussing the eruption process. In addition to the energy release due to the crustal deformation, seismic, and plume rise activities, estimate of the volcanic block discharge energy is important not only for volcanological standpoints but also for preventing disasters. For these purposes, we need to evaluate the velocity, direction and mass distribution of the ejected blocks at the exit of a crater. However, in most cases, it is hard to measure directly such quantities during an eruption. Therefore, the distribution of volcanic blocks landed on and around the crater has been investigated after the eruptions to reproduce the kinetic aspects of the ejected blocks.

Ballistic curves of volcanic blocks are controlled by effects such as the direction of the principal axis of ejection, the velocity and direction of the wind, the air resistance to the blocks and the direction dependence of the initial velocity of ejection. Among these effects, the air resistance plays an important role for accurately estimating the initial velocity. Matuzawa (1934) pointed out that the air resistance applied to a flying object should be treated as a vector. However, previous works (*e.g.*, Nagata, 1938; Minakami, 1942; Iguchi *et al*., 1983; Iguchi and Kamo, 1984) did not take account of this problem.

In the present paper, we numerically calculate synthetic ballistic curves of volcanic blocks for various combinations of the above-mentioned parameters including the air resistance treated as a vector. Referring to these results, we tried to reproduce detailed kinematic aspects of the ejected blocks at the 1982 and 1983 eruptions of Sakurajima Volcano, Kyushu, Japan.

2. Ballistic equation of ejected blocks

In this chapter, we count up some important factors which affect the ballistic curves of ejected blocks: air resistance, wind velocity, direction of the initial velocity of ejection, inclination of the principal axis of explosion and size of the blocks.

2−1 Equation of motion considering the air resistance

Matuzawa (1934: in a revised paper of Matuzawa, 1933) pointed out that the air resistance working to a flying object should be treated as a vector, although he did not present any detailed form. Then, we formulate an equation of the motion of a flying object following the Matuzawa's suggestion. In the present paper, we treat intensity of the air resistance is in proportion to the second power of the block velocity, V^2, while the direction of the applied force is opposite to that of the flight, $-\boldsymbol{V}$. Thus, we propose the equation of motion as:

$$m\frac{d\boldsymbol{V}}{dt}=m\boldsymbol{g}+\boldsymbol{f}, \tag{1}$$

where m, $\boldsymbol{V}$, and $\boldsymbol{g}$ are respectively the mass of block, the flying velocity of block and the acceleration of gravity, respectively. $\boldsymbol{f}$ means air resistance vector. The inertial air resistance $\boldsymbol{f}$ is expressed as:

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